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Long-term effect of periodic fire on nutrient pools and soil chemistry in loblolly-shortleaf pine stands managed with single-tree selection

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ABSTRACT

Prescribed fire can be an important tool for managing loblolly (*Pinus taeda* L.) and shortleaf pine (*Pinus enchinata* Mill.) stands in the southern United States but few studies have reported the impact of repeated prescribed fires in stands that are routinely thinned or partially harvested. We compared nutrient pools and soil chemistry in portions of three uneven-aged loblolly-shortleaf pine stands that had received dormant-season prescribed fires every one to four years (high frequency fire) during a 20 year period to portions of these same stands in which fire was excluded (control). The stands had been managed using single-tree selection and harvested on a 5-year cycle since the establishment of the prescribed fire treatments. Sixteen months following the last prescribed fire, forest floor nutrient pools were 42–49% less in the high frequency fire than control treatment. Understory vegetation recovered rapidly and approximately 34 months following the last fire, understory biomass and nutrient pools were similar within the two treatments. However, the repeated use of prescribed fire effectively reduced the density of saplings which resulted in a 78–85% reduction in sapling biomass and nutrient pools in the high frequency fire compared to the control treatment. Chemistry of the surface (15 cm) mineral soil was similar in the two treatments indicating that the prescribed fires had little impact on the mineral soil. Periodic harvesting may have ameliorated changes in mineral soil P, Ca, or Mg availability that have been reported to occur with long-term, repeated application of prescribed fires in southern pine forests. Reductions in forest floor and sapling nutrient pools associated with the prescribed fire likely had little impact on tree productivity or soil sustainability since foliar nutrient concentrations of the overstory trees in the two treatments did not differ and the potential losses were small compared to surface soil pools.

1. Introduction

Prescribed fire is a valuable tool used to manage forests in the southern United States. Melvin (2012) reported that during 2011, prescribed fires were utilized on more than 2.6 million ha of forestland in this region. Fire has historically been used to reduce fuel loads and risks of wildfire (Wade and Lunsford, 1989; Stanturf et al., 2002; Fowler and Konopik, 2007), prepare sites for tree planting or regeneration (Wade and Lunsford, 1989; Stanturf et al., 2002), and control competing vegetation (Van Lear, 2000; Stanturf et al., 2002). More recently, prescribed fire has been used to restore and maintain fire dependent forest ecosystems (Van Lear, 2000; Haines et al., 2001; Stanturf et al., 2002) and promote habitat for threatened or endangered species (Haines et al., 2001). Restoration of fire-dependent southern pine forests often requires removal of overstory and/or midstory trees because fire exclusion has resulted in hardwood encroachment and dense midstories that impact fire regimes and understory plant composition (Stanturf and Madsen, 2002; Guldin et al., 2004; Mitchell et al., 2006). Following initial restoration treatments and reestablishment of appropriate fire intervals, periodic harvesting of overstory trees can provide economic returns while also maintaining appropriate understory composition and diversity (Mitchell et al., 2006). Even when southern landowners are not interested in reestablishing fire-dependent ecosystems, they often employ partial harvesting and prescribed fires to promote economic income from their property while improving wildlife habitat or recreational opportunities.

Research on the direct impacts of fire on nutrient regimes has generally shown that as fire severity and fuel consumption increases the loss of nutrients by volatilization, offsite convection

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of particulates, and/or rapid mineralization followed by accelerated leaching escalates (Neary et al., 1999; Fischer and Binkley, 2000; Carter and Foster, 2004; Certini, 2005). Although frequent applications of prescribed fires in southern pine stands likely reduces fire severity and thus direct loss of nutrients, long-term (10–30 years) repeated application of low severity fires has been found to alter nutrient regimes, biogeochemical processes, and soil chemistry (McKee, 1982; Schoch and Binkley, 1986; Bell and Binkley, 1989; Binkley et al., 1992; Liechty et al., 2005). However, these studies have not addressed the combined effect of tree harvesting and periodic fire on nutrient pools or nutrient availability. Only the study by Liechty et al. (2005) included a partial overstory harvest and the harvest in their study occurred prior to rather than during the period of prescribed fire application.

To better understand how the combination of periodic fire and harvesting impacts nutrient regimes, we quantified nutrient pools and soil chemistry in three uneven-aged loblolly-(*Pinus taeda* L) shortleaf pine (*Pinus echinata* Mill.) stands in the Upper Gulf Coastal Plain. One portion of the stands received eight dormant-season fires during a 20 year period while in another portion of the stands fire was excluded. Stands were managed using single-tree selection with a five-year cutting cycle. The study was initially established to determine the impact of harvesting and fire on pine regeneration and establishment.

2. Methods

2.1. Study area

The study was conducted within three 16-ha loblolly-shortleaf pine stands located at the Crossett Experimental Forest in Ashley County, Arkansas (33°02′N, 91°56′W). Elevation is approximately 53 m above mean sea level with nearly level topography. The growing season is 240 days and mean annual rainfall is 140 cm with typical wet winters and dry autumns. Daily temperatures average 22 °C during the growing season while temperatures average 11 °C during the dormant season (USDA, 1979). Soils within the three stands are Bude and Providence silt loams, classified as a Glossaquic Fragiudalf and a Typic Fragiudalf, respectively (USDA, 1979). An impervious layer occurs within these soils between a depth of 46–102 cm which impedes root growth and internal drainage. The site index for loblolly pine is 27 m at age 50.

Overstory and midstory vegetation within the study area is dominated by loblolly pine and shortleaf pine with minor amounts of red maple (*Acer rubrum* L.), oak (*Quercus* spp.), sweetgum (*Liquidambar styraciflua* L.), and sassafras (*Sassafras albidum* (Nutt) Nees) (Tappe et al., 1995; Cain et al., 1998). The shrub understory is predominantly American beautyberry (*Callicarpa americana* L.), honeysuckle (*Lonicera* spp.), greenbrier (*Smilax* spp.), blackberry (*Rubus* spp.), and sumac (*Rhus* spp.) (Tappe et al., 1995; Cain et al., 1998).

2.2. Site history

Our study was conducted within three 16-ha research sites established by the USDA Forest Service Southern Research Station in 1980. The stands at these sites were used to assess the effect of overstory basal area retention and dormant-season prescribed fire on pine regeneration and growth in uneven-aged loblolly-shortleaf pine stands managed using single-tree selection (Cain, 1993). These stands had been managed using single-tree selection and fire exclusion from the late 1930s to the 1960s. From 1970 to 1980 no harvesting or hardwood control was performed. Cain and Shelton (2002) provide additional management history of these stands prior to the initial establishment of overstory retention and prescribed fire treatments.

2.3. Study design

In 1980 each of the three 16-ha study sites was divided into four 4-ha burn interval treatments; control (no fire), high frequency (1–4 year interval), moderate frequency (5-year interval), and low frequency (10-year interval). Only the control and high frequency fire (HFF) treatments were used for our study. Thus, two levels of the prescribed fire treatment (control and HFF) were implemented on each of the three study sites.

The initial prescribed fire was applied in January 1981 (Cain, 1993). A total of eight prescribed fires were set prior to the initiation of soil and vegetation measurements for our study. For these eight prescribed fire events, fine fuel moisture ranged from 6 to 25%, mean fire line intensities calculated according to Byram (1959) ranged from 189 to 489 kW m^{-1}, and general fire intensity relative to typical fire behavior in these types of stands varied from low to moderately high for the eight burn dates. During the last fire (Oct. 27, 1998) fine fuel moistures was 13%, mean fire line intensity was 189 kW m^{-1}, 3–5 min wind speeds averaged 2 km h^{-1}, and fine intensity was low. Addition fuel and weather conditions for the prescribed fires can be found in Cain (1993) and Cain and Shelton (2002).

Until 1990 uneven-aged single-tree selection was used to maintain each of four residual basal areas (9, 14, 18, or 23 m^2 ha^{-1}) in one of four 1-ha plots in the HFF and control treatments in each 16-ha site. After 1990, all of the 1-ha plots were maintained at 14 m^2 ha^{-1}. Uneven-aged regulation methods used to select trees for retention in the plots can be found in Cain et al. (1998) and Cain and Shelton (2002). Harvesting occurred in the summer or fall of 1982, 1987, 1992, and 1997. Our study utilized the 1-ha plots that were assigned the 14 m^2 ha^{-1} retention treatment. Therefore the study plots were managed at the same residual basal area since the initiation of the prescribed fire treatments in 1981.

Competition control is an important component of uneven-aged management to ensure adequate establishment of shortleaf and loblolly pine regeneration (Reynolds et al., 1984). Thus to maintain similar densities of hardwood competition following the initiation of the prescribed fire treatments, all living hardwoods with ground line diameters of >2.54 cm were injected with Tordon® 101R (0.03 kg/l of picloram and 0.12 kg/l 2,4-D) during the spring of 1981 in both the HFF and control treatment plots. In addition, Arsenal® AC herbicide (0.42 kg ha^{-1} active ingredient) and Accord® (1.68 kg ha^{-1} active ingredient) was broadcast by rubber-tired skidders in the control treatment during September of 1991 to reduce hardwood competition.

2.4. Sample collection and measurement

To avoid edge effects, the majority of the sample collection and vegetation measurements occurred within an interior 0.65 ha portion of each 1-ha plot. Destructive sampling of large vegetation (sapling size trees) occurred between the borders of the 1-ha treatment and 0.65-ha measurement plots.

Forest floor (O_i and O_{e+a} soil horizons) was collected on March 2000 approximately 16 months following the last prescribed fire. A total of twelve 0.1 m^2 frames were located within each 0.65-ha measurement plot. Six frames were positioned at 10 m intervals along each of two transects (approximately 15 m apart) that were centrally located in a measurement plot. The O_i and the O_{e+a} horizons were separately removed from the interior of the frames and placed in bags. The materials collected from the two locations in the adjacent transects were combined. The samples were returned to the laboratory where the O_i horizon material was sorted into pine foliage, woody debris, herbaceous, broadleaf woody foliage, and reproductive materials. The O_i and O_{e+a} material was then dried at 65 °C for 48 h and weighed. Materials from the five groups